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No 5

The Canadian Oil and Gas Sector

SECTORAL TECHNOLOGY STRATEGY SERIES

NO. 5 THE CANADIAN OIL AND GAS SECTOR

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Highlights

- Energy prices are expected to remain stable throughout the 1990s. But as reserves of conventional oil in Canada and other non-OPEC countries are depleted, the OPEC countries, which have more than half the world's reserves of conventional oil, will again have the potential to manipulate world supplies and prices. Hence, R&D and technology strategy in the oil and gas sector are of key importance.

- Oil and gas R&D can be categorized as "upstream" or supply-oriented R&D aimed at long-term development of oil and gas as strategic resources, and "downstream" or demand-oriented R&D focused on products and processes, energy conservation, and environmental protection. A major issue in developing a technology and R&D strategy for Canada is to find the appropriate balance between upstream and downstream R&D.

- Canadians own and control a minority of their oil and gas industry, and this limits the ability of Canadians to influence R&D decisions. Since 63.9 per cent of the industry is foreign controlled, decisions to increase R&D investment in Canada's petroleum sector must involve foreign decision makers.

- Company size is a major factor determining involvement in R&D. Most small to medium-sized conventional oil and gas companies do little R&D. Of the large, non-integrated conventional oil and gas companies, those that are affiliated with U.S. companies tend to do little R&D in Canada.

- Available statistics indicate that the ratio of R&D expenditures to sales in the Canadian oil and gas sector is about 60 per cent of the ratio in the U.S. sector. But comparing countries' R&D/sales ratios on an industry-wide basis can be misleading. In at least one U.S.-based multinational firm, the ratio of R&D to sales is higher in the Canadian subsidiary than in the U.S. parent. In any case, what is more important is to determine whether the existing level of R&D effort in Canada is appropriate for future needs.

- Total R&D spending by the Canadian oil and gas industry is approximately $300 million annually, the same annual amount that one representative U.S. multinational firm spends. About 25 per cent of the R&D funded by Canadian operations and included in Canadian R&D expenditure statistics is conducted outside Canada, partly because the appropriate facilities or skills are lacking in Canada, but mainly because of specific research mandates given out to regional laboratories by major multinationals.

- The focus of upstream research is on ways to exploit "unconventional" oil resources, oil that is not economical to extract at existing world prices and with existing technology. Canada has the best unconventional resources in the world in terms of cost and technological accessibility. These resources could potentially meet all of North America's energy needs.

- Upstream research is costly and risky. Payoffs may not come for 20 or 30 years, or they may not come at all. But successful upstream research would ensure that Canada's unconventional oil resources would be accessible when needed. All North America would gain from such accessibility.

- Downstream R&D involving new products and processes is particularly important in the light of more demanding product specifications (e.g., reformulated gasoline) and environmental standards (e.g., automotive emissions standards).

- New environmental standards for refined products (e.g., reformulated gasoline) are putting increased cost burdens on some smaller refiners at a time when they do not have the profit margins to cope with them. Since the whole Canadian industry is only the scale of one medium-sized multinational, it may be relatively vulnerable to such changes.

- In downstream research and development, it may be desirable to rationalize Canadian industry in order to achieve necessary "critical mass" to upgrade facilities and fund R&D — even if such R&D is limited to supporting an adopt/adapt technology strategy.

- Opportunities exist in downstream R&D that could lead to commercially viable payoffs within the next 10 years. These include research into alternative fuels like methanol and compressed natural gas to meet more stringent environmental regulations and satisfy the performance characteristics of fuels for specialized engines, as well as R&D in such areas as export-oriented exploration and development services, and energy systems management. Downstream R&D should be linked to these and other industrial benefits.

- Emphasizing research to capitalize on commercial opportunities will require greater flexibility in the industry in areas such as contracting-out, encouraging divisions of larger firms to undertake more responsibility for profit making ("contracting-in"), supporting small and medium firms in their export marketing efforts for services and/or specialized equipment, and developing the management capability to be a full-service-line sector.

- The main technology strategy used throughout the oil and gas industry worldwide is adopt/adapt. Innovation tends to be mainly in process technology but also includes new products such as new fuel and lubricants. Pressure to innovate is driven by characteristics of specific feedstocks, environmental regulations, energy reduction, and regional product demand. Technology is usually made available to other firms through licensing. Licensing royalties can provide a significant income for oil companies.

- Canadian firms derive little of their cash flow from licensing. This may indicate that Canadian research efforts are not showing significant direct commercialization success right now, even if valuable for the longer run. In a few cases, there are important indirect returns to the Canadian sector through intra-corporate technology "trading," when the Canadian subsidiary has a specific world product mandate.

- Canada cannot depend on an outside R&D leader to develop and license much of the technology it needs, because Canadian resources, particularly the unconventional ones, present some unique technological problems.

- Canada has developed considerable expertise in oil sand upgrading and sour gas processing and is developing expertise in tight sands/deep sands gas extraction, offshore exploration and development, and alternative fuels such as methanol. In general, Canadian expertise is more upstream oriented.

- Investment in specific projects, such as further oil sand extraction plants (e.g., OSLO) and offshore drilling (e.g., Hibernia) must be very carefully timed. Total capital investments in such large-scale operations amount to billions of dollars, and the Canadian economy cannot easily absorb such demands for credit in the foreseeable future unless there is reasonable prospect of adequate returns.

- In upstream R&D, with payoffs beyond 10 years, the roles of resource companies, refiners, research institutions, Canadian federal and provincial governments, and overseas governments must be defined to ensure that research efforts are coordinated and costs are shared equitably. This will likely require a concerted action plan that would specify technology goals, memoranda of understanding between all the players, and reasonable accountability levels.

Background to the Sectoral Technology Strategy Series

In the emerging "new" economy of the 1990s, successful high-value businesses in advanced nations are being driven by innovation, propelled by spending on new products and processes. Their business strategies centre increasingly on specialized knowledge and skill in finding the right "fit" between their unique blend of core technologies and particular markets.

Where does Canada stand in this rapidly evolving new environment of changing linkages and relationships? The poor innovative capacity of Canadian industry has long been a concern of the Science Council of Canada, going back to its 1971 report *Innovation in a Cold Climate*. The Council re-emphasized this concern in 1988. It focused its attention on the potential for action at a sectoral level in its statement *A Sectoral Approach to Innovation*. It argued:

> There is growing recognition by industry and government in Canada of the key role played by technology and R&D in domestic and international competition. The Science Council considers that it is primarily the responsibility of industries to raise the degree of domestic technological sophistication and the level of R&D. Nevertheless, governments can help business to sustain long-term competitiveness both by building partnerships with individual firms and by generating consensus on the formulation of innovation strategies for the various industrial sectors. The intent is not for government to tell business what to do, but to facilitate business cooperation in a process of self-help. The process of building consensus on a strategy for a particular sector will involve close and on-going consultation with industries about the current role of technology and R&D in the sector, the opportunities foreseen, and the nature of the sources, stimuli, and forms of technological innovation. Obviously, to be successful, separate innovation strategies will be needed for each sector. The Science Council hopes that the process of building consensus will generate commitment and collective will concerning priorities, areas for cooperation, and agenda for action.

This statement proved to be an important step in the path that subsequently led the Council to undertake a major Sectoral Technology Strategy project.

In 1989, Industry, Science and Technology Canada, at a time of heightened concern for the state of Canadian competitiveness and serious questioning about the low level of Canada's gross expenditures on research and development as measured against other advanced countries, agreed to provide the main funding for this project. It also stipulated the selection of sectors on which it would like the project to focus.

Each report in this Sectoral Technology Strategy Series draws in part upon analyses commissioned by the Science Council of Canada from contractors, designed to reveal the key dynamics driving technological innovation in the sector and influencing company technology strategies. Each report has also benefited considerably from the comments and advice submitted by the many external reviewers from business, universities, and government, who are recognized in the Acknowledgements.

Commentary on the Sectoral Technology Strategy Series and R&D Targets

The Sectoral Technology Strategy Series has analysed 15 Canadian sectors. On the basis of this experience, the Science Council of Canada makes the following points with regard to Canadian R&D performance and the issue of setting sectoral R&D targets.

- Canadian firms, when grouped by sectors, generally perform much less R&D than their trade competitors. Using the indicator of R&D as a percentage of sales, Canadian firms undertake R&D at a rate about one-third to one-half the rate of their leading international sectoral competitors. The notable exception among those sectors analysed is telecommunications.

- In some product lines or specific technologies certain absolute threshold levels of R&D and capital investment must be reached if the effort is to be considered to have a chance of making a commercial payback. High thresholds are apparent in some parts of sectors such as telecommunications (central office switches), automotive parts ("Tier 1" supplier status), oil and gas (reformulated gasoline standards by refineries), and electronics (integrated circuit foundry). Such absolute thresholds cannot be clearly expressed as a percentage of sales.

- The reasons for the lower level of R&D spending by firms in most of the 15 Canadian sectors are: choice of business and technology strategy (which, in part, leave Canadian companies as essentially non-participants in many higher value-adding segments); the relatively small size of Canadian firms; the high absolute thresholds of R&D expenditure required to be a meaningful player, especially for innovative technology strategies; and the degree of foreign ownership of Canadian firms (especially important in the case of the automotive vehicles and parts sectors).

- The lack of R&D relative to other countries affects Canadian competitiveness, but it is only one of many factors, such as capital and labour costs, quality design, good marketing, and management, that interact to affect overall competitiveness. Nevertheless, the contribution of R&D, or more precisely, technology-based innovation, is becoming more pronounced throughout the global economy and Canada continues to fall behind. The low level of R&D is especially detrimental to the capacity of Canadian resource-based sectors to compete with higher-value, differentiated products, leaving them vulnerable to adverse shifts in costs beyond their control, such as a higher exchange rate.

- Major potential does exist for Canadian industry to make additional R&D investments. However, fulfilling this potential depends heavily on the vision and capability of management to make strategic use of technology, to speed the firms' innovation process, to work more closely with suppliers and "demanding customers" all the way to the end of the product chain, and to build core capabilities in incremental innovation and R&D. Canadian firms have not yet fully grasped the implications of the emerging new "lean enterprise" or "agile producer" strategy. To follow this new strategy involves seeking to offer maximum value to customers. It requires integrating the skills base of a knowledgeable workforce with flexible management structures that stimulate cooperative initiatives within and between firms to match customer needs.

- The dominant technology strategies being followed by Canadian firms in these sectors are of adopt and adapt. Innovation technology strategies are not very extensive (telecommunications is again an exception) and hardly any firms focus on breakthrough strategies to enhance competitiveness. Overall, these 15 sectors show little attempt at diversification out of existing product lines as opposed to making such products more efficiently.

- Governments can set sectoral R&D targets in the hope of stimulating enhanced industrial performance, shifts in business strategy, and greater commitment by the private sector to R&D. However, private sector R&D is only meaningfully undertaken in conjunction with a full complement of associated private and public sector actions ranging from improved design and production to finance and marketing. Doing more R&D will not be productive unless linked to a broader corporate technology strategy that is carefully designed to support the firm's business objectives. Otherwise, the corporation cannot, and will not, marshal the complementary investments required to reap the benefits of the R&D. It is the firm that must commit R&D resources.

- Setting sectoral R&D targets becomes more difficult as the boundaries between sectors are breaking down, through technological advances, regulatory change, and firm restructuring. Larger and more diversified firms that dominate modern industrial R&D perform R&D that might be allocated to any of several sectors. Examples include the textiles and materials R&D performed by large Japanese steel firms, the electronics R&D by automotive-vehicle firms, and the software R&D by telecommunications firms. Canadian governments have quite correctly encouraged higher levels of industrial R&D in Canada. In view of the rapid pace of scientific advances and technological change, plus the role of system interdependencies and synergies between technologies, setting R&D targets does not appear to be a task warranting the intensive effort, cooperation, and, ultimately, commitment that would be required by federal and provincial governments and private sector organizations.

List of Sectoral Technology Strategy Series Reports

No. 1 The Canadian Telecommunications Sector
No. 2 The Canadian Automotive-Parts Sector
No. 3 The Canadian Iron and Steel Sector
No. 4 The Canadian Automotive-Vehicle Sector
No. 5 The Canadian Oil and Gas Sector
No. 6 The Canadian Petrochemicals and Resins Sector
No. 7 The Canadian Banking Sector
No. 8 The Canadian Nonferrous-Metals Sector
No. 9 The Canadian Forest-Products Sector
No. 10 The Canadian Machinery Sector
No. 11 The Canadian Food and Beverage Sector
No. 12 The Canadian Electric-Power Sector
No. 13 The Canadian Consulting-Engineering Sector
No. 14 The Canadian Electronics Sector
No. 15 The Canadian Computer Software and Services Sector

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Introduction

The world has lived through two "oil crises" in the last 20 years that made the issue of oil supplies a cause célèbre for the global economy. But in 1991 the price of oil was stable and may even have been under downward pressure. Will Canadians ever experience another shortage with rapidly rising prices, or will technological developments help manage oil and gas supplies in a socially acceptable way? And if supplies remain stable, what are the implications for R&D in the Canadian oil and gas sector? Would research still be a priority for the sector? What R&D opportunities really exist?

The main objective of this report is to provide an indication of the technology strategies of the leading firms, to examine how the Canadian sector performs in R&D compared with its main trade competitors, and to analyse the major reasons for any differences and how they affect competitiveness in Canada's oil and gas sector.

The Importance of Oil

The 20th century is often described as the age of petroleum — an age when oil, supplemented by natural gas, toppled coal as the primary power source for the industrial world. Today, about $3 billion worth of oil products are used each day. The oil industry is the world's biggest business.[1]

The petroleum era of the 20th century can be divided into three periods:

1. Rapid growth, from 1900 until 1973. Oil consumption almost doubled every decade and oil prices declined. Petroleum became the main fuel of economic growth and essential to everyday life, first in North America, then in Europe, and finally throughout the world.

2. Instability, beginning in 1973. The Arab oil embargo of 1973 and the Iranian revolution of 1979 pushed the average world price of oil from $2 per barrel in the early 1970s to $35 in 1981.[2] The results illustrate vividly the perils of excessive energy costs — worldwide recession and spiralling debt, even for the wealthy OECD[3] nations, and a punishing blow to the development prospects of the oil-poor countries of the Southern Hemisphere. But despite the burden of higher prices, the role of oil in the world economy continued to grow, and the economic and political influence of the Middle Eastern countries mushroomed.

3. Supply surpluses and price declines after the 1979-1981 round of price increases. Almost overnight, a seller's market became a buyer's market and prices began to slide for the first time since 1971. During the 1980s, the world enjoyed a large and growing surplus of production capacity and prices that in some cases returned to their pre-1973 levels.

The instability of oil prices did considerable damage to the world economy. Because of the dominance of oil in energy supply, the price of oil tends to set the price for all types of energy. But as oil prices and energy costs rise, demand for capital rises at a disproportionately faster rate. In Canada in the early 1970s, energy costs represented approximately 5 per cent of gross national product (GNP), 3.5 per cent being returns to capital and the rest operating costs. The doubling of real oil prices during the 1970s meant that energy costs rose to about 7 per cent of GNP. Of this, 5.5 per cent was capital. It is not easy to transfer 2 per cent of GNP from consumption, government expenditure, or other capital investment into energy capital in just five to seven years. There are structural and technological limitations on the flexibility of any given capital stock. The OECD countries as a whole went through a similar shift in economic activity. Given current high real interest rates, any future oil price rises could be severely detrimental to Canada and other nations if they are accompanied by disproportionate parallel increases in demand for capital investment. Canada is experiencing difficulty in financing even current capital needs — as evidenced by rising international debt and high real interest rates.

The drop in oil prices during the 1980s was largely unforeseen by energy planners. In the late 1970s, opinion was almost unanimous that further oil price increases and continuing heavy oil dependence were inevitable. Research groups, private companies, and governments all expected oil prices to surpass $50 per barrel during the 1980s.[4]

It is hard to imagine how most of the world's energy planners and forecasters could have been so wrong about something so central to the world economy. In retrospect, energy analysts would have done far better applying simple economic theory to their oil forecasts. Eight years of rapidly rising oil prices, culminating in spot market prices of over $40 per barrel in the early 1980s, created an enormous incentive to reduce oil consumption and to find and develop fresh oil and gas reserves. Oil consumption stabilized or dropped, partly because of the severe economic recession, but largely

because of increased energy efficiency. In the industrialized countries, energy intensity — the amount of energy used to produce a unit of GNP — fell by 20 per cent between 1973 and 1985. In the United States, for example, GNP grew 40 per cent while energy consumption remained constant.[5] Energy efficiency made it possible for the world to climb out of the severe 1981-1982 recession, and led to a 75 per cent decline in the real price of oil between 1981 and 1986.[6] Despite recent sharp reductions in output from two major producers — Iraq and Kuwait — prices have still shown downward pressure. It appears that the world has a much more flexible system today, as this would not have happened in the 1970s.

However, the dramatic collapse of oil prices in the 1980s may precipitate another oil crisis. The efforts of the industrialized nations to reduce their reliance on OPEC oil has produced a lopsided, unsustainable situation. Oil fields in North America and Western Europe have been producing at full capacity. But they contain only 8 per cent of the world's proven conventional oil reserves. In contrast, the oil fields in the Middle East, which represent over half of global reserves, are operating below capacity. Industrial countries will therefore increase their reliance on Middle Eastern oil as non-OPEC reserves decline. This is why political developments in the Middle East have become increasingly important among the oil-poor industrialized nations, as witnessed in the recent Persian Gulf conflict.

Although the current apparent stability may be just a temporary reprieve from higher oil prices, it provides an opportunity for industrialized countries to plan for a more stable and secure energy future. If the opportunity is missed, the OECD nations could face an economic downturn similar to the oil shocks of the 1970s, but under much less favourable circumstances.[7] Since 56 per cent of the world's proven oil reserves are in the Persian Gulf, world oil power will inevitably be centralized in this region, which could eventually dominate world markets.[8]

Overview of the Global Oil and Gas Sector

The Global Oil and Gas Market

In 1990, world energy demand was the equivalent of 109 million barrels of oil per day (Mbbl/d), as shown in Table 1. Oil demand totalled 50 Mbbl/d or 46 per cent of total energy demand. Coal represented 28 per cent of world energy demand. Natural gas was in third place at 20 Mbbl/d or 18 per cent of total energy demand.[9]

Table 1. World energy demand by type (1990)

	Million barrels per day	Percentage of total demand
Oil	50	46
Coal	24	22
Natural gas	20	18
Nuclear	7	6
Hydropower and other	8	7
Total	109	100

Source: Purvin and Gertz, Inc. and Hycarb Engineering, "Sectoral innovation strategy for the oil and gas industry," report prepared for the Science Council of Canada, December 1990, p. II-8.

The Oil Market

Petroleum and petroleum products are significant factors in international commerce. In 1989, 47.5 per cent (22.1 Mbbl/d) of world crude production of 46.5 Mbbl/d was traded internationally.

Energy industry trade patterns have developed largely from the combination of geology, transportation economics, and the location of markets. Oil refineries are generally located near markets, because the costs of moving crude are lower than the costs of moving refined products. International petroleum movement is estimated to comprise 70 per cent crude and 30 per cent petroleum products.[10] The transportation costs for crude oil and petroleum products are rarely more than 10 per cent of the delivered cost at current crude oil prices.[11] The total storage capacity for both crude and refined products is about 2 per cent of annual production. Petroleum tends to be consumed as it is produced, and there is no buffer to smooth out major changes in supply or demand.

Crude oil trade declined in the early 1980s in the wake of the 1979 oil shock, but it recovered in the latter years of the decade. U.S. imports, for example, declined from more than 6 Mbbl/d in 1978 to a low of 3.1 Mbbl/d in 1985, mainly because of decreased consumption. European imports declined from more than 11 Mbbl/d to 5.9 Mbbl/d during the same period, due to a 3.8 Mbbl/d decrease in demand and a 21 Mbbl/d increase in European production. Since 1985, however, both U.S. and European imports have steadily increased, rising to 5.8 Mbbl/d in the United States and 7.1 Mbbl/d in Europe in 1989. These imports are expected to continue rising as demand grows and domestic reserves are exhausted.[12]

Crude oils from different locations vary in their characteristics, requiring different production processes and making them appropriate for differing final products. However, all crude oil is separated and converted, by processes such as distillation and catalytic cracking, into three major categories of products:

- light end products with high hydrogen content and low specific gravity, including gasoline used as fuel;
- middle distillates, which include diesel fuel, kerosene, and home heating oil; and
- heavy ends or residuals with high specific gravity, which have limited use as fuel for low-speed engines (e.g., marine engines) and industrial processes.

The supply of raw energy materials — crude oil and pipeline-entry natural gas — is traditionally described as the "upstream" end of the industry. The processing or refining of these materials into specific products, such as gasoline, is known as the "downstream" end of the industry. The OECD nations consume about 73 per cent of total world refined products. About 30 per cent of OECD consumption is gasoline, and 50 per cent of this is consumed by the United States and Canada. Outside North America, distillate is the major product, closely followed by residual fuel oil. Kerosene is widely used for heating and cooking in many non-OECD nations.[13]

Although disruptions in crude oil supply and rapid price increases over the past two decades have resulted in increased use of alternative forms of energy, petroleum will probably remain the dominant energy source for the next 20 to 30 years.

Oil Reserves

The standard measure of conventional world oil resources is proven reserves. This category includes all oil that is contained in known reservoirs and extractable at current prices and with current technology. Each year new oil discoveries are added to proven reserves, and the oil actually extracted is subtracted. Proven world oil reserves increased rapidly throughout the post-World War II period — rising from 76 billion barrels in 1950 to 664 billion barrels in 1973. Since the mid-1970s, however, proven reserves have increased only 5 per cent, even though higher oil prices have encouraged exploration and the quantity extracted each year has declined. The bottom of the conventional oil barrel is now visible, marking a major milestone in the petroleum age.

About 56 per cent of the world's proven oil reserves are in the Middle East, and about 95 per cent of proven reserves are in just 20 countries. Oil remains one of the most unequally distributed resources.[14] Table 2 shows the location of major proven conventional oil reserves as of 1989.

The Organization of Petroleum Exporting Countries (OPEC) controls three-quarters of proven crude oil reserves, including all recent additions. Reserve estimates for non-OPEC nations, including the former Soviet Union, have been revised downward. The former Soviet Union consumes 15 per cent of world oil and has been increasing its production.

Oil does exist in the ground beyond all these figures. These are the so-called unconventional resources — heavy oil, oil sands, and oil shales. Heavy oil is crude oil whose viscosity (flow propensity) is sufficiently high that it cannot be extracted by the usual methods. Its chemical composition is similar to that of conventional oil. Proven heavy oil reserves in North America are; for the United States, 20 billion barrels; for Canada, 553 million barrels; and for Mexico, 4.1 billion barrels. These reserves are not all economically exploitable at the present, although some fields are currently in production.

Table 2. Reserves of conventional oil and cumulative production by region (1989) (billions of barrels)

Region	Oil produced to date	Proven oil reserves
Middle East	160.0	660.3
Former Soviet Union	n.a.	59.9
Latin America	60.9	125.2
United States and Canada	135.5	42.4*
Africa	45.3	58.8
Asia/Oceania	36.7	46.8
Europe	14.9	18.4
World		1 011.8

Source: British Petroleum, "Review of world energy," London, 6 March 1990.

* U.S. reserves of 36 billion barrels; Canadian reserves of 6.4 billion barrels.

In addition, there are large deposits of oil sands in Canada (Athabasca) and Venezuela and large deposits of oil shales in the United States, especially in Utah and Colorado. Hundreds of billions of barrels of oil are locked up in the sand and rock that these two resources represent — 900 billion barrels in Athabasca, two trillion in the U.S. shales. These deposits are not commercially exploitable on a large scale at present, although some production from Canadian oil sands is under way — approximately 225 000 barrels per day (bbl/d). This is a small output compared with the total world output of 46.5 Mbbl/d (1989) but arguably the most technically interesting in light of its unconventional nature.

For the foreseeable future, control over the movement of oil in world trade will hinge largely on control in the Middle East — principally Saudi Arabia, Iran, Kuwait, and Iraq.[15]

The Natural Gas Market

Natural gas provides one-fifth of all commercial energy worldwide. It is an efficient energy source that is flexible enough for use in industry, transportation, and power generation. Moreover, it generates fewer pollutants, including carbon dioxide, than any other fossil fuel. Natural gas releases 14 kilograms of carbon dioxide for every billion joules, whereas oil and coal release 20 and 24 kilograms, respectively.

Natural gas is a much less important factor than oil in international commerce. At present, transportation costs often make up more than half of the delivered wholesale cost.[16] International trade in natural gas cannot increase much until cheaper means of transportation are developed or the gas can be converted into higher-value products that justify transport costs.

Natural Gas Reserves

Proven worldwide reserves of natural gas stood at 3.4 quadrillion cubic feet, equivalent to 590 billion barrels of oil, in 1985. This is only 15 per cent lower than proven world oil reserves, but with present technology natural gas supplies only half as much energy.[17]

Many industry experts expect conventional sources of natural gas to last four or more decades, and many electric utilities consider natural gas the best near-term substitute for oil as a fuel for some power plants. Known conventional reserves, like oil reserves, are concentrated in a few nations — nearly 70 per cent in the Middle East and the former Soviet Union.[18]

Natural gas is the only fossil fuel for which reserve estimates have risen significantly in recent years — 34 per cent in a decade. Large gas discoveries in the former Soviet Union rank as one of the big energy success stories of the past decade. The Soviet gas reserves are the energy equivalent of 250 billion barrels of oil, more than 10 years' worth of world oil consumption, and represent 43 per cent of world gas reserves. Soviet gas production doubled during the past decade, providing energy for industry, power plants, and households.[19] Natural gas could also provide much needed foreign currency for the former Soviet Union.

Instability in Oil Markets

Over the last 20 years, oil prices and markets have been characterized by extreme volatility and uncertainty. In the late 1960s and early 1970s, the United States exhausted its surplus oil capacity. Before this, the U.S. surplus had long provided the Western world with the security of a surge capacity that could be called upon in time of crisis — as in World War II and the much more limited crises of 1951, 1956, and 1967.[20]

The disappearance of this security margin meant ever-increasing reliance on oil from the Middle East. Between 1960 and 1970, free world oil demand grew by 21 million barrels per day. Production in the Middle East (including North Africa) increased by 13 Mbbl/d over the decade, which meant that two-thirds of the huge increase in demand was satisfied by Middle East oil.[21] The oil shocks of the 1970s were thus the logical consequence of the limited and declining size of U.S. reserves and the resultant vulnerability of oil consumers everywhere to those controlling foreign oil.

Later in the 1980s, as surpluses appeared, concern shifted to the other side of the market. Prices fell and energy expenditures in the OECD countries dropped from 12 per cent of gross domestic product (GDP) in 1980 to only 8 per cent in 1988.[22] Oil-exporting countries began seeking secure outlets for their oil.

Indeed, the most surprising development in world oil markets is not that consumption has declined or that prices have fallen, but that, despite large reductions in demand and new supplies of oil, prices have not collapsed as they did as when similar gluts occurred in the copper and uranium markets. But the explanation is quite simple. Although OPEC has lost its capacity to set world oil prices directly, the cartel has drastically cut production and given up market share to prevent a price collapse.[23]

Saudi Arabia is the dominant "swing producer," having propped up oil prices by removing as much as 7 Mbbl/d from the world oil market. Saudi Arabia's oil production fell from 10 Mbbl/d in 1980 to less than 4 Mbbl/d in 1985 — the lowest level in 18 years.[24] Overall, OPEC reduced production from 26.8 Mbbl/d in 1980 to 16.1 Mbbl/d in 1985.[25]

While OPEC has proved able to sustain its role as a successful cartel, member countries are experiencing declining economic growth and diminished power in the world economy. Total OPEC revenues fell from a peak of $275 billion in 1981 to around $80 billion annually in the late 1980s. This constitutes a real economic crisis for countries that obtain 95 to 100 per cent of their foreign exchange from oil revenues and that have based government spending programs on oil revenue projections that proved to be much too high.[26]

Despite the recent conflict in the Persian Gulf, there is still downward pressure on the price of oil. Purvin and Gertz, Inc. and Hycarb Engineering forecast a price of around $15 per barrel by early 1992. Although oil production in Iraq and Kuwait has almost ceased because of the Gulf war and its

aftermath, Saudi Arabia has increased production and could continue to exert downward pressure on oil prices for a considerable time.

On the other hand, long-term trends look less favourable for oil-importing countries. One of the most ominous trends in recent years is the accelerated depletion of some of the world's most limited oil reserves, all outside the Middle East. During the 1970s, the high price of oil made it economical to greatly increase oil drilling in dozens of non-OPEC countries. Many of these wells will soon reach a point of diminishing returns. Oil production in some regions, including North America, Europe, and the former Soviet Union, may begin to fall steeply during the next decade.

The current energy situation may therefore be inherently unstable. Low oil prices undermine future investments in energy efficiency and alternative energy sources, slowing the move away from oil. A growing number of analysts believe that oil markets are so weak that oil prices could drop to between $10 and $15 per barrel. Low oil prices have already reversed the worldwide move away from oil dependence, laying the groundwork for a future energy crisis.[27]

A note worthy phenomenon of current oil markets is the widening spread in prices between sweet, light crude and heavier/sourer grades. Crude oil is categorized into different grades according to its viscosity and contamination by sulphur. A light, sweet crude has relatively low viscosity (i.e., it flows readily) and a low sulphur content. Heavier grades resist flow, and sour grades contain relatively high contamination. The high-quality light, sweet crude typical of Saudi Arabia and Texas is used to establish the reference or "marker" price of oil in world markets.

In the past, relatively heavier or sourer grades (produced from conventional fields) had to be sold at a modest discount — perhaps 10 per cent less than the marker price. Kuwaiti oil, for example, is a relatively heavy grade and has not commanded quite as good a price as neighbouring Saudi oil. At present, however, the spread between light, sweet crude and heavy, sour crude is much greater — up to 50 per cent.[28] If the marker price is $18 per barrel, the price for sour/heavy crude can be as low as $9 per barrel.

Declining supplies of light, sweet oil mean that many refiners will soon be facing rising costs, because they cannot accept heavy/sour crude unless they add the facilities to do considerable extra upgrading. This will require significant extra capital investment, which is not feasible at a time when overall prices in the world oil and oil product value chain are under downward pressure.

This dilemma may be a partial explanation of the widening price spread. The world price of oil is falling overall, reflecting total supply/demand dynamics. But the market may be anticipating a not-too-distant day when light, sweet resources have been consumed, and therefore it is already accepting a major premium for this grade.

In fact, recent shifts in world oil markets have some rather disturbing long-term implications. The rate of depletion of the world's most abundant oil resources has slowed, but depletion of some of the scarcest and most strategically important reserves has accelerated. OPEC's share of the world oil market is predicted to reach 55 per cent in the 1990s, up from 27 per cent in 1985.[29]

Growing independence from Middle Eastern oil in the 1980s provided a false sense of security, as it occurred largely at the expense of greater long-term dependence. The lower the current Middle Eastern share of the market, the greater its share at the end of the century, when many countries will be running out of oil. The Persian Gulf could then move back into the driver's seat, with world oil resources more limited than at any time in recent history.[30]

Supply and demand conditions suggest an equilibrium price for Middle East light crude oil of about $18 per barrel (in constant 1990 dollars) in the intermediate term, according to Purvin and Gertz, Inc. and Hycarb Engineering. If prices are substantially above this level, demand for oil will decline because of conservation efforts and further displacement by alternative energy sources, as happened before the crude oil price downturn in 1986. If, on the other hand, prices are significantly

lower, oil will begin replacing coal in industrial boilers and less effort will be made to develop new energy supplies. Either of these extremes will cause price corrections.[31]

Purvin and Gertz, Inc. and Hycarb Engineering also claim that market stability depends on a stable and adequate production level in the OPEC countries. If the world petroleum balance requires less than 22 Mbbl/d of OPEC output, prices become very unstable because the fiscal needs of many OPEC members cannot be satisfied at these low rates of production. Various members will seek to market crude in excess of the quota, and prices will weaken. A production level of 22 to 27 Mbbl/d is sufficient to satisfy most members' needs and makes adherence to a quota more probable. If OPEC output above 27 Mbbl/d is required, many of the members are at maximum sustainable production rates and pressure on prices is upward.

OPEC has two strategy options under conditions of relative oil shortage: a production ceiling strategy or an income ceiling strategy.

In a production ceiling strategy, the OPEC countries would agree to hold output to a fixed level. As world demand for oil increased, oil prices would rise until demand returned to the ceiling level. In other words, demand alone would determine the new price. But consumers would find ways to conserve oil and substitute alternative energy sources, and R&D would focus on expanding these options and reducing their cost.

On balance, the experience of the 1980s suggests powerful limits to the ability to drive up prices by such a strategy. Technology can get around oil, if need be, except in the very short term (two years or less). Moreover, there are strategies for dealing with the short term (such as developing strategic storage reserves or "locking-in" some resources, with necessary compensation to their owners). By and large, if OPEC were to announce a production-ceiling strategy, even in a strengthening oil price environment, the world economy could cope.

The income-ceiling strategy could be much more dangerous to the global economy. In this scenario, OPEC would control production in order to maintain a ceiling on revenues. A strengthening oil price would lead to outright cutbacks in production. The decline in oil availability would inevitably be much more severe in this case, since each cutback would drive prices higher, creating a vicious cycle of upward price movements and declining oil supplies. It is hard to imagine how the world economy could adjust to such a strategy.

The two strategies are not mutually exclusive. Some OPEC producers might prefer a production ceiling, but others with a more limited ability to absorb funds might prefer the income ceiling. The market outcome could be complicated, with a mix of supplies controlled by one or the other strategy interacting with the short-run and long-run price elasticities of oil demand and alternative energy supplies (i.e., the changes in oil demand and in alternative energy supply induced by changes in oil prices).

World demand for OPEC crude is now approximately 23 Mbbl/d and will gradually increase. Although prices may increase in nominal terms, Purvin and Gertz, Inc. and Hycarb Engineering forecast that they will remain about constant in 1990 dollars until late in the decade. Crude oil prices are expected to continue to fluctuate seasonally around $18 per barrel (Mideast Marker FOB), and OPEC output is projected not to exceed 27 Mbbl/d until the late 1990s. In the early years of the 21st century, crude prices can be expected to increase in real terms.

The Global Oil and Gas Industry

The Oil Industry

The pivotal role of oil in the world economy explains the high level of government involvement in the industry, ranging from the British government's role in establishing British Petroleum to ensure fuel

supply for the Royal Navy, to the tight grip exercised over the Japanese refining industry by the Ministry of International Trade and Industry. State involvement has grown rapidly since the 1960s as nationalism induced expropriation of industry operations throughout the world. State-owned companies today participate in all phases of the industry. Many have gradually been transformed from pure instruments of state control into commercial, profit-maximizing entities almost indistinguishable from private companies.[32]

Saudi Aramco is a good example. Originally U.S.-owned, Saudi Aramco is now wholly owned by the Saudi government. Saudi Aramco owns all Saudi oil reserves, which constitute about a quarter of the world's proven oil reserves, and is the world's largest oil exporter. In addition to supplying crude oil, the firm is involved in refining and gasoline retailing through its 1988 joint venture with Texaco Inc. Star Enterprise. This joint Saudi Aramco/Texaco venture owns or has long-term leases on 1500 Texaco stations in the United States, making it the second largest gasoline retailer in the country.[33]

Value-added relationships in energy industries reflect the extractive nature of the basic business. The bulk of the value added comes from finding and producing oil and gas. The wellhead value accruing to the producer represents more than 60 per cent of the final value of petroleum products. The remaining 39 per cent represents crude transportation, refining, and product marketing. Crude transportation and product marketing margins have been relatively stable, while refining margins are volatile, ranging from a loss of $0.93 per barrel in 1984 to a profit of $0.74 per barrel in 1988.[34]

Companies can generally be distinguished by the business segments in which they participate and the degree of integration between those business segments. Although most of the value of crude oil accrues to the producer, it can only be realized when the oil is marketed. Since most of the oil industry's history has been characterized by excess production capacity, producers have a strong incentive to establish secure outlets for their production. As first illustrated by Rockefeller's Standard Oil Trust, control of the entire chain — from production through marketing — has provided companies with strong competitive advantages. Today, national companies in oil-producing countries, such as Saudi Aramco, are developing similar vertical integration by establishing downstream ventures.

Table 3 summarizes the extent of vertical integration achieved by a representative selection of different types of crude oil and refined product companies.

Table 3. Vertical integration of representative crude oil and refined products companies

Type	Exploration and production	Crude transportation	Refining	Product transportation	Product marketing	Examples
Independent producer	X					Clyde Petroleum
Pipeline		X		X		Buckeye
Independent refiner			X			Salomon
Refiner-marketer			X	X	X	Sinclair
Fully integrated	X	X	X	X	X	Exxon

Source: Purvin and Gertz, Inc. and Hycarb Engineering, "Sectoral innovation strategy for the oil and gas industry," report prepared for the Science Council of Canada, December 1990, p. I-21.

The petroleum refining industry tends to be dominated by large integrated multinationals that undertake R&D and technology transfer on a global basis. As a result, the technology of petroleum refining has an international character. Some nonintegrated companies participate in the Canadian refining industry on a regional basis, acquiring the requisite technology through processor licences or other means.[35]

An important company type not directly involved in the crude oil and refined products market, but deeply involved in the business, is the independent engineering and construction firm. Such companies as Fluor, UOP, and Kellogg provide engineering and construction services in all the business segments. They also perform much of the industry's process development research, which they license to industry participants. They thus disseminate technology throughout the industry and allow companies to benefit from research performed by others.[36]

The Natural Gas Industry

The value-added chain in the natural gas industry is much less tilted toward the producer, because of the high capital and operating costs of gas pipeline and distribution systems. Gas values along the chain in the U.S. market for 1989 were 40 per cent for exploration and production, 31 per cent for gathering and transportation, and 29 per cent for distribution.[37]

The natural gas industry exhibits a lower degree of integration than crude oil products businesses, probably because of the regulated status of most pipelines and distribution operations. Utility regulations governing transmission and distribution lower the attractiveness of integration to producers. Companies tend to specialize as either producers, pipeline providers, or distributors.[38]

On an energy-equivalent basis, the international gas trade was approximately 16 per cent of the world oil trade in 1989. Gas trade is conducted on a much more regional basis than oil, as the capital-intensive and fixed nature of much of the hardware limits the flexibility of natural gas movements. However, over the next 20 to 30 years, the international gas trade will probably increase faster than the international oil trade.[39]

Overview of the Canadian Oil and Gas Sector

Canada's high standard of living, cold climate, and great distances all combine to make it the world leader in per capita consumption of energy, with the United States in second place. The average Canadian used the energy equivalent of almost 45 barrels of oil in 1988.[40]

Canada has the distinct advantage of approximate self-sufficiency in oil. Oil imports in eastern Canada are approximately offset by exports from western Canada. In gas, Canada produces enough for domestic requirements and exports to adjacent U.S. markets. About 60 per cent of the total value of Canadian crude oil and natural gas is consumed domestically, and 40 per cent is exported.[41] Canada has the potential to develop additional oil supplies that could move it into a surplus situation,[42] although these would be from unconventional sources.

Canada is a small player in terms of global oil trade, but it is a significant supplier on a regional basis to the United States. In particular, the U.S. Midwest represents an important market for Canada's surplus heavy crude oil production. Access to this nearby market is a great advantage to the Canadian crude oil production industry because Canada lacks a domestic refining capability for such heavy oil. On a global basis, Canada is an important source of natural gas, with most exports moved by pipeline to the United States.[43]

Canada's oil and gas industry is characterized by diversity. All areas are dominated by the major integrated international oil companies, followed by 15 to 20 medium-sized firms with activities primarily in the upstream sector.

Overall, the Canadian oil and gas sector must cope with instability. The upstream resource supply industry carries a high debt load and sells a large portion of its production in the export market. As a result, cash flow and profitability are heavily influenced by interest rates, exchange rates, and a commodity price set in the export market. Return on capital for the total upstream sector fell from 7.7 per cent in 1984 to 3.0 per cent in 1989. Foreign-controlled companies have generally exhibited higher profits than Canadian-controlled firms. The downstream product and processing sector, despite a lower debt load, was less profitable than the upstream sector prior to 1986, but it has been more profitable since.

The Oil Sector

The petroleum industry, with revenues of $50.2 billion, represented 12.2 per cent of Canada's real GDP in 1989.[44]

Canada's light crude production is below domestic demand. Some light crude is exported from western Canada to the northern United States, but imports to eastern Canada exceed these export volumes. Almost 85 per cent of Canada's light crude production is in Alberta, but Alberta production is declining and is forecast to fall from 780 000 bbl/d in 1989 to 522 000 bbl/d by 2005.[45] Most of Canada's heavy crude production is exported.

Drilling activity in the Canadian oil industry has declined precipitously since 1985, and most of the decline has been in oil exploration. In 1985, a total of 11 471 wells were drilled. By 1990 the number had fallen to 5881.[46] One reason was the drop in the price of oil from $36.88 a barrel for Canadian crude at the start of 1986 to $24.17 at the start of 1990. Another reason was the general view that fewer attractive oil targets remain in western Canada. Some companies have cut back on their efforts to find oil, preferring to explore for gas instead. The level of exploration for gas has not declined. In 1990, the industry completed 2383 gas wells; 2444 were completed in 1985.

The oil industry will probably not return to the exploration and development drilling levels recorded in 1985, because conventional oil exploration in western Canada is not attractive to large

companies at prices below about $30 a barrel. Not many companies expect prices like that within any sort of commercial timeframe.[47]

Canada's conventional oil reserves are declining and at current world prices its unconventional (oil sands) and frontier reserves are all far too expensive in terms of recovery and processing costs to compete with oil from conventional sources, particularly that from the Middle East. There is little likelihood that the industry will develop unconventional and frontier reserves in the near future without government assistance.

From a technological viewpoint, however, Canadian oil sand extraction and development have been important. Synthetic crude production at the Syncrude and Suncor plants has continued to grow. This is the result of improvements in organizing the production process as well as productivity gains. Syncrude's 30 000 bbl/d capital addition program came on stream in late 1988. Plans for another 75 000 bbl/d expansion have been deferred indefinitely. The combined production of the Syncrude and Suncor plants is now around 225 000 bbl/d, which is about 20 per cent of total Canadian oil supplies.[48] This is the world's most significant production from unconventional sources, and it seems fair to say Canada is in the lead in tapping such sources. The Orinoco oil sands of Venezuela have not yet been exploited commercially, and existing U.S. production from oil shales is minimal.

The Other Six Lease Holders (OSLO) project is a $4.5 billion plan to build an oil sands plant near Fort McMurray, Alberta. Cost of production will be an estimated U.S.$16-25 a barrel. In contrast, oil can be pumped in Saudi Arabia for less than U.S.$5 a barrel. The federal government has refused the OSLO consortium the $650 million it requested to start construction.[49]

Frontier crudes include those of the Beaufort Sea and the east coast. The Beaufort Sea crude reserves are over 500 million barrels. In 1988, plans to develop these crudes were in progress, but the project has since been deferred indefinitely. Unless world oil prices rise significantly, the economic viability of Canadian frontier crude is questionable.

The first commercial project of Canada's east coast will be the Panuke project, operated by LASMO Canada Inc. Parts of the offshore project have been committed. Panuke should produce 30 000 bbl/d of light crude/condensate for part of the year, starting in 1992 and ending around 1998.

The major east coast commercial project is the Hibernia field off the Newfoundland coast. The federal government has invested $2.7 billion to develop Hibernia.[50] Agreements were recently signed between the operator, Mobil, and the federal and provincial governments. Legislation has been enacted, and major contracts have been awarded. The project should come on stream in 1996 and reach 110 000 bbl/d at full production.

Ian Doig, editor of an energy newsletter and a leading analyst of the Canadian energy industry, describes Hibernia as "a project that will produce the most expensive oil in the world." Doig claims it will cost about U.S.$20 (1991) to produce a barrel of oil at Hibernia, whereas 75 per cent of world crude oil production is produced for less than $5 a barrel.[51] Perhaps this will eventually be a good investment, but getting the timing right is vital and Canadian credit markets seem to be stretched already, judging from real interest rates.

Fourteen companies in Canada operate oil refineries. These include three large integrated companies (Esso, Petro-Canada, and Shell), five regional companies with a resource affiliate, and six small companies with relatively limited resource affiliation. The profitability of the refining industry over the last decade has generally been unsatisfactory in terms of return on invested capital.

There are implications for refiners in the expanded use of oil sand feedstocks in Canada. With current technology, synthetic crude from oil sands produces good-quality high-octane gasoline but relatively lower quality middle distillates such as diesel fuel. This has led to concerns that diesel fuel cetane ratings will fall in western Canada. This can be overcome through technical means such as additional natural gas hydrogenation, but costs would inevitably rise. That could be bad news for the

western trucking industry, because even a modest price increase would seriously weaken the industry's ability to compete with U.S. trucking firms.

The Natural Gas Sector

Overall, domestic and export consumption of Canadian natural gas has grown steadily in recent years, except for a 10 per cent drop in 1986; consumption increased by almost 40 per cent from 1984 to 1989. In 1989 both domestic demand and exports rose to all time highs, with domestic consumption reaching 2540 billion cubic feet per year and exports of natural gas to the U.S. reaching 1350 billion cubic feet per year. With deregulation and a number of projects that will soon increase export pipeline capacity, both export and domestic markets are expected to continue growing to the end of the century. Exports to California and the northeastern United States are likely to grow rapidly.[52]

Traditionally, Canada has produced a net surplus of natural gas liquids (NGLs). The two major sources of propane and butane in Canada are natural gas production and petroleum refineries. The concentration of propane and butane in Alberta natural gas is expected to decline with time as the production of associated gas decreases. This decline should be partially offset by the NGL-rich Caroline reservoir in Alberta, discovered in 1987 and expected to be fully on stream by 1993.

Gas processing means upgrading the raw gas resource by recovering co-products such as natural gas liquids and sulphur while producing natural gas that meets pipeline specifications. In contrast to the Canadian oil refining industry, the gas processing industry is made up of many companies. In Alberta, where 85 per cent of Canadian gas is produced, there are 550 major installations recovering NGLs. Over one-third require sweetening to remove hydrogen sulphide, and more than 50 produce marketable quantities of sulphur.[53]

Summary

The Canadian oil and gas industry produces and delivers oil and gas to both domestic and international markets at prices competitive with those of other energy alternatives. Canadian consumers in energy-intensive industries can buy oil and gas in the domestic marketplace at prices that permit them to be competitive. Some of these industries are also major exporters of energy-intensive commodities. All this indicates that the oil and gas sector is competitive in world markets.

Canadian oil and gas companies can generally pursue the exploration and development of Canada's conventional oil and gas potential as efficiently as international competitors. Although most Canadian companies do not have the financial, technical, or human resources to undertake large developments such as offshore or Arctic exploration and production and oil sands on their own, some have participated in these ventures. Several Canadian companies have participated in international oil and gas exploration and production. The oil and gas service sector appears to be competitive, and there are expanding opportunities for the export of technology, services, and equipment.

R&D and Technology Strategy in the Global Oil and Gas Sector

The technology strategy of most firms in the oil and gas sector throughout the world is to "adopt and adapt." The industry view is that no single company, however large, can adequately research all the different resource bases and chemical and mechanical processes applicable to the industry. Final products are perceived to be relatively undifferentiated commodities (even if industry insiders are keenly aware of subtle but important differences). Accordingly, it makes sense to license new technology developed elsewhere — this technology is virtually always process-oriented. Each firm usually conducts some R&D in a specialized area, hoping that success will lead to significant royalty income.

R&D in the oil, gas, and related industries is conducted in four broad areas: upstream R&D to increase oil and gas supplies; demand-side R&D to improve energy efficiency or develop alternative energy sources; environment R&D to minimize harmful side effects of oil and gas production and use; and downstream R&D into new products and services for industrial development.

Increasing Oil and Gas Supplies

Cost is the most important criterion in purchase decisions for almost all oil and gas products. Gasoline purchasers, for example, tend to be indifferent to the technological achievements involved in producing the gasoline and do not benefit from product quality in excess of minimum requirements. The same is true for almost all energy products. Since product differentiation is difficult, R&D efforts are largely focused on the supply side and are concentrated in three areas:

- Resource identification[54] and development. This area receives the greatest amount of research expenditures, since the bulk of the product's final value accrues to the resource producer.

- Cost reduction. Any reduction in cost directly increases the producer's or processor's income, as the value of the product is set in international markets. Refiners and processors must subsist on relatively small and volatile margins.

- Yield improvement. This applies to higher recovery from an existing reserve or to higher or better yield of products in a refinery or processing facility.[55] This factor is becoming increasingly important because of higher performance and environmental standards.

Two primary trends will shape future upstream R&D activities. First, companies must try to replace production from existing properties. As older producing regions are more thoroughly exploited exploration activities move to more remote, higher-cost regions and unconventional sources. Second, companies must search for ways to increase recoveries from known deposits. The vast amount of oil left in place after primary and secondary recovery is an exceptionally attractive target.

Increasing recovery from known reservoirs can be attractive, even if fairly expensive, because the infrastructure is already in place. Enhanced recovery techniques and methods of exploiting resources that are currently uneconomic will continue to receive industry attention. The rapid proliferation of horizontal drilling, made possible largely by improvements in measurement-while-drilling technology, has brought new life to several once-moribund producing

regions. The rapid spread of horizontal technology illustrates the industry's relatively unrestricted access to new developments, largely through contractor services.[56]

North America has been drilled more extensively than any other region in the world. As a result, new finds are smaller and finding costs are higher than elsewhere. To replace production, companies must look to frontier areas in North America or to underexploited international regions. Frontier areas include the Arctic regions and deep-water offshore areas. The technological challenges of exploring and producing oil in these areas have spawned a great deal of research and many innovative techniques, such as the development of tension-leg platforms for deep-water production.

The move to more remote regions has also spurred efforts to reduce exploration costs through increased efficiency. These efforts include gaining better understanding of basic geological processes and refining seismological techniques to reduce the probability of dry holes.

The other major sources of oil are unconventional: heavy oil, oil sands, and oil shales. There are known oil sands in the Athabasca region of Alberta and the Orinoco fields in Venezuela, and there may also be deposits in Siberia. There are known oil shales in Tennessee, Utah, Colorado, and the former Soviet Union. As the oil in the sands or shales is not under pressure, it cannot be recovered through conventional extraction processes. Considerable R&D effort is being expended to find economical ways of extracting the oil. Canada is a leader in oil sands R&D and is extracting and processing oil from at least one deposit. Extraction from oil shales is still at the experimental stage.

There are heavy oil deposits in Saskatchewan and Alberta, the former Soviet Union, the Middle East, and South America. These oils have a high specific gravity and are difficult and costly to extract and refine. Modifications of conventional technologies can be used for some deposits.

Higher oil prices would make it more economical to exploit heavy oil and unconventional resources. For all unconventional sources, refinery processes must be changed and new ones developed to accommodate the raw material and turn it into a useable product.

Gas reserves have also become more expensive to develop, as new reserves are generally of lower quality and in more remote locations. Lack of access has prompted processors to increase the portability of processing plants. The skid-mounted plants currently in use can be taken readily to remote locations and moved around to take advantage of opportunities. Additional industry resources have been devoted to increasing the value of low-quality gas reservoirs containing high amounts of carbon dioxide, hydrogen sulphide, or other contaminants. Improved sulphur recovery with lower operating and capital costs will be pursued throughout the industry as development of fields such as Shell Canada's Caroline field in Alberta becomes more common.[57]

Improving Energy Efficiency

Table 4 shows the decline in energy intensity (defined here as the ratio of energy consumption to GNP) in five OECD countries from 1973 to 1985. The price shocks and fears of supply shortages that began in 1973 led to efforts to reduce oil consumption through greater energy efficiency and substitution of alternative energy sources. These efforts contributed more to the oil glut and price fall of the 1980s than the expansion of oil production in non-OPEC countries or the decline in demand resulting from economic recession. Energy efficiency was the single most important factor.[58]

Since 1973 there has been almost no net increase in oil and gas energy supplies. Most market-oriented industrial economies have improved their energy efficiency by 15 to 30 per cent. Efficiency displaces $250 billion worth of oil, gas, coal, and nuclear power annually in industrial countries. These improvements in energy efficiency are the single largest factor in reducing global dependence on oil.[59]

Table 4. Energy intensity of selected national economies (1973-1985) (in megajoules per 1980 dollar of GNP)

	1973	1985	Percentage change 1973-1985
Canada	38.3	36.0	-6
West Germany	17.1	14.0	-18
United Kingdom	19.8	15.8	-20
United States	35.6	27.5	-23
Japan	18.9	13.1	-31

Source: International Energy Agency, *Energy conservation in IEA countries*, Paris: OECD, 1987. Quoted in Christopher Flavin and Alan B. Durning, "Building on success: the age of energy efficiency," *Worldwatch Paper* 82, March 1988, 8.

Energy efficiency can offer enormous competitive advantages to a country. For example, in 1986, energy consumption represented 10 per cent of GNP in the United States, but only 4 per cent of GNP in Japan. If energy intensity were as low in the United States as in Japan, it would free an additional $200 billion of GNP for investment in other areas and would lower the cost of U.S. goods. The energy differential gives the average Japanese product an automatic cost advantage of about 5 per cent in the U.S. market.[60]

Energy efficiency also has important environmental implications. Improved efficiency means less urban air pollution and less acid rain. Many opportunities have not yet been exploited, and it may still be possible to continue the pace of energy conservation enhancements.

The greatest potential for energy efficiency and reduced environmental damage is in the transportation sector, since the motor vehicle is the single largest consumer of oil. About half the world's oil is consumed by a fleet of 500 million road vehicles. Growth of this fleet has consistently outpaced population growth. Interest is growing in developing commercially viable vehicles capable of 60 or more miles per gallon (mpg) and vehicles that run on compressed natural gas, hydrogen, and electricity.[61]

Further gains in vehicle efficiency could come from a variety of technologies such as continuously variable transmissions and direct-injection diesel engines. For example, the "adiabatic" engine reduces or eliminates energy loss in the engine's cooling system. Test vehicles developed by Volkswagen and Volvo have achieved combined city/highway fuel economy of 62 mpg or better. Raising fuel efficiency of cars in the United States alone to the technically achievable level of 50 mpg could cut global gasoline consumption by almost one-quarter (assuming no growth in the total fleet.)[62]

However, falling oil prices and ample supplies have noticeably diminished the urgency to make automobiles more fuel-efficient. Since 1982, gains in fuel economy in the United States and most other OECD member states have fallen short of the impressive advances made between 1974 and 1981.

Although heating and electricity production can make use of alternative fuels when oil prices go too high, the world's cars and trucks run almost exclusively on petroleum-based fuels. The dependence of motor vehicles on oil sent gasoline prices shooting upward during the oil price shocks of the 1970s. As oil absorbed a larger share of world import bills, car sales dropped. Global car

production fell by about five million vehicles, or almost one-fifth, after the first oil price surge in 1973 and slightly less in the wake of the second crisis in 1979. By 1986, however, gasoline consumption began rising again, reaching a new peak in 1986. Gasoline is now in plentiful supply in most countries. A number of technological changes in the transportation sector and shifts in energy consumption patterns contributed to this turn-around.

Since the opportunities for discovering large new oil deposits or developing alternative transportation fuels in sufficient quantity are limited, the industrialized countries responded to dire predictions of continued oil shortages with a number of technological changes. Innovations in the design of motor vehicles, such as the use of lighter-weight materials, radial tires to reduce resistance to rolling, and exterior designs to decrease aerodynamic drag, greatly increased energy efficiency. Fuel efficiency in the United States increased from 13 mpg in 1973 to 18 mpg in 1985, allowing fuel consumption to remain constant over the period despite a 33 per cent growth of the vehicle fleet. Advanced refining processes were developed to extract more gasoline from each barrel of crude oil. Gasoline accounted for 33 per cent of oil products consumed in the OECD countries in 1986, up from 28 per cent in 1976.

Over the same period, energy demand outside the transportation sector shifted away from oil use — energy from nuclear, coal, and hydroelectric plants completed since 1972 now displaces some 12 million barrels per day of potential global oil demand.

Energy efficiency gains means reduced sales for oil companies. But oil may remain competitive with alternative energy sources such as electricity. The one R&D area that is unambiguously positive for vertically integrated, privately held oil companies is finding ways to increase the output of premium gasoline and other higher-value products. Since the early 1970s refinery losses have diminished from about 20 per cent to about 8 per cent of throughput.

Developing Alternative Energy Sources

Potential alternative fuels include methanol, ethanol, propane, natural gas, hydrogen, and synthetic fuels produced from natural gas, gas liquids, coal, and biomass. Laboratory efficiencies of solar photovoltaic cells have roughly doubled since the 1970s and are expected to improve further.[63]

Methanol and compressed natural gas (CNG) offer the most promising short-term development opportunities. They cause less pollution than conventional fuels and have the performance characteristics required by high-performance engines. Methanol remains one of the most promising options. Its chemical formula is CH_3OH; it is closely related to methane (natural gas), which is CH_4. Natural gas is an ideal feedstock for its production; the insertion of an oxygen atom gives methanol some powerful characteristics, including storability in liquid form.

Methanol has a great resistance to premature detonation. It has an extraordinarily high octane rating, about 108 compared with 91 and 92 for current premium unleaded gasoline. This permits very high compression ratios in automotive engines — up to 14:1. In tests by the Ford Motor Company, methanol improved the acceleration of several different cars. Typically, methanol allows a more advanced ignition spark, which increases efficiency. Moreover, methanol's superb anti-knock characteristics allow it to be blended with diesel fuel in compression-ignition engines. Of all oil products, diesel fuel is likely to go into short supply first, as heavier and/or more sour crudes generally make poorer distillates.

The drawbacks usually ascribed to methanol are its relatively low energy content, its corrosiveness, and its affinity for water. The first implies theoretically poor fuel mileage in any vehicle, but this has not been observed in practice nearly as much as theory would suggest. Methanol-fuelled vehicles can usually attain 90 per cent of the fuel economy of equivalent gasoline-fuelled

vehicles, apparently because the extra oxygen atom promotes more complete combustion. Corrosiveness is a more difficult problem, but substituting more durable materials for rubber, neoprene, or mild steel in fuel lines and tanks can likely solve it. Lastly, while methanol can undergo a so-called "phase separation" in the presence of water (i.e., it does not stay mixed in gasoline blends), again in practice such separation is less of a problem because the normal agitation of the rolling vehicle is enough to sustain the blend. Moreover, Ford has developed sensors that can automatically adjust the running of the engine regardless of momentary changes in fuel blends.

From an environmental standpoint, methanol has a different and, with one exception, generally superior emissions signature. It does not readily produce photosynthesized smog, which is why more than one major initiative is under way in California to mandate the use of a significant proportion of methanol and other alternative fuels over the next 10 years. The one environmental drawback to methanol is its propensity to produce aldehyde emissions — which are likely carcinogenic — although this may be corrected through engine modifications.

A 1984 study sponsored by the former Ministry of State for Science and Technology indicated that methanol was close to cost-competitive with gasoline. Tighter emission standards would enhance methanol's edge, at least in regional markets. Countries with large natural gas reserves, like Canada and the former Soviet Union, ought to be very interested in this fuel. It has major possibilities.

Early in 1991, General Motors, Ford, and Chrysler announced the formation of a consortium to develop battery technology for electric cars. The goal is to develop electrical energy systems capable of providing future generations of electric cars with a range and performance competitive with those of gasoline-powered internal combustion engines. Initial funding will be about U.S.$35 million and is expected to rise to U.S.$100 million annually by 1993.[64] General Motors is now actively planning production of its "Impact" electric commuter car.

Alleviating Environmental Damage

Technologies need to be developed to alleviate two regional-scale environmental disturbances associated with fossil fuel combustion: acid deposition and urban smog. Solutions are also being sought for a third and potentially more devastating disturbance: increased global warming caused by rising levels of carbon dioxide and other greenhouse gases (i.e., gases that capture heat radiating from the Earth and trap it near the surface). Carbon dioxide is emitted whenever fossil fuels are burned, and although coal adds proportionally more carbon dioxide to the atmosphere than do oil and gas, emissions from oil and gas combustion are a greater problem because these fuels are more widely used.

The problem of global warming is difficult to resolve, in part because there is disagreement over how real and dangerous the threat is and therefore how much effort should be devoted to coping with it. Technologies to ameliorate the effects of fossil fuel combustion on acid deposition, urban air pollution, and global warming must be pursued.[65] High priority should be given to reducing emissions of sulphur dioxide, nitrogen oxides, and hydrocarbons from fossil fuels.

The environmental issues that will have the biggest impact on the energy industry are:

- removal and recovery of greenhouse gases;
- overall water management, including the recycling of production water, and tailings pond management;
- lease/site abandonment; and
- reduction of emissions of nitrous oxides, sulphur dioxide, carbon dioxide, and particulates.

Waste management, particularly in the Prairies, is an ongoing concern. The norm for heavy oil production is becoming 100 per cent re-use of production water. Oil sands plants are under pressure

from the Alberta Energy Resources Conservation Board (ERCB) to reduce tailings. Site contamination and reclamation are of importance in both the resource and manufacturing sectors of the energy industry. Improvements in sulphur recovery efficiency will continue at gas plants and at oil sands and refining operations as the ERCB and other provincial and federal groups address the question of sulphur dioxide emissions and acid rain.[66]

Environmental goals are starting to have a major influence on the refining industry. The most important of those goals is the reduction in atmospheric pollution from the combustion of transportation fuels. The use of unleaded gasoline has reduced emissions from the levels of the mid-1960s, but further reductions are called for.

In the past year, reformulated gasoline has moved from relative obscurity to the forefront of efforts to reduce automotive emissions.[67] It provides a way for oil companies to retain the automotive fuel business instead of losing it to alternative fuels such as methanol. "Cleaner" fuels also reduce pressure on automotive manufacturers to find ways to lower vehicle emissions. [68]

Use of reformulated gasoline has been promoted by recent amendments to the *Clean Air Act* in the United States. The amendments also direct attention to alternative fuels such as methanol — research in the early 1980s indicated that oxygenated fuels could significantly decrease carbon dioxide emissions in vehicles lacking sophisticated air pollution control equipment because the oxygen contained in the fuel seems to promote more complete combustion.

Methyl-tertiary-butyl-ether (MTBE) is a gasoline blendstock produced from the reaction of isobutylene and methanol. MTBE is currently the most widely accepted oxygenate for gasoline blending, but it may not be the final answer to environmental problems. Many plants to produce MTBE have been announced or are in the engineering stage around the world, including a world-scale plant under construction in Edmonton. Canada has the resource potential to support more than one world-scale MTBE facility. The isobutylene would be produced from isomerization and dehydrogenation of field butanes; the methanol, from natural gas. Supplies of both butane and natural gas are forecast to be good in the long term.[69]

Gasoline reformulation is likely to spread through the developed nations if it proves successful in North America. In that case, new refining capabilities and investments will be required. Investment will be directed toward processes such as improving octane without increasing aromatics. But more demanding product specifications are likely to be introduced to reduce aromatics and benzene content. Benzene content will probably be restricted first, due to its health risks, and the remaining specification changes will be phased in gradually.[70] Non-vertically integrated refiners who lack appropriate scale will have trouble making these changes economically.

Developing New Products and Services

The two oil crises precipitated greater oil and gas exploration and revitalized the whole question of managing energy supply chains. Countries with expertise in such management, including Canada, gained from the new demand.

This sort of management expertise is still valuable and likely to become more so, despite stable oil prices. Many regions might be worth exploring for fossil fuels, including Australia and New Zealand, South America (Argentina, Falkland Islands), the South China Sea, and the Chinese mainland. Geophysical exploration and energy management as a whole are growth industries.

Energy service companies (including engineering contractors) play a key role in disseminating technology throughout the industry. These companies often develop technology and make it widely available on a licensed basis. Since the service company's best interest lies in maximizing the number of licensees, an individual licensee is generally unable to gain a lasting competitive advantage. Instead,

technology must be shared with all competitors. For example, the Hughes rock bit did not make its inventor a wealthy oil producer but brought wealth through sales to oil companies. The most successful companies were those that identified this key development earliest and adopted it most widely.[71]

R&D and Technology Strategy in the Canadian Oil and Gas Sector

The R&D and technology strategy employed by the Canadian oil and gas sector must be consistent with the evolving feedstock supplies in Canada and globally and must be appropriate for evolving product specifications worldwide. It must also be consistent with both short-term and long-term conditions and must respond to environmental concerns.

Unfortunately, these requirements present some serious contradictions. The challenge in defining an agenda for Canada is to find the appropriate trade-off between the long-term development of oil and gas as strategic resources on the one hand, and the need for commercial payback to shareholders on the other.

Canada's R&D and technology strategy must deal with some specific contradictions:

- Canada's ability to produce conventional crude oil is declining, while production capabilities in the Middle East, particularly in Saudi Arabia, are rising.

- Canada has arguably the best unconventional resources in the world (oil sands), in terms of cost and technological accessibility, but at current oil prices these sources cannot be developed economically.

- Canada could supply much of North America's needs from its unconventional sources, but it lacks the financial means to develop those sources singlehandedly.

- Canada's refinery capability is under pressure technologically and economically, yet even more upgrading will be required if its unconventional sources are to be exploited.

- Canada has the capability to produce sufficient natural gas both for the domestic market and substantial exports. But natural gas is not readily transportable in its raw form, and higher-value products are required if it is not to remain "locked-in" under the ground.

- The technology strategy used in the oil and gas sector worldwide is one of adopt and adapt. But Canadian resources, particularly the unconventional ones, present some unique technological problems. Therefore, Canada cannot rely on an outside R&D leader to develop and license the technology that will be required to use these resources.

Is the Canadian R&D effort helping to resolve these contradictions? And how can one judge what level is enough?

Table 5 presents Canadian and U.S. expenditures on oil and gas R&D as a percentage of operating revenues. Some allowance must also be made for differences in definitions of R&D in the two countries. The data indicate that Canadian R&D expenditures range from 54 to 69 per cent of U.S. R&D expenditures. However, the U.S. statistics apply only to the 23 largest companies, whereas the Canadian statistics are based on all companies reporting to the Petroleum Monitoring Agency. If data on the overall U.S. oil and gas industry were collected, the U.S. R&D performance expressed as a percentage of operating revenue would probably be lower. Purvin and Gertz, Inc. and Hycarb Engineering believe the quantitative differences between Canadian and U.S. R&D efforts are less than implied in the table.[72]

Table 5. R&D expenditures in the United States and Canada as a percentage of operating revenue (1982-1989)

	1982	1983	1984	1985	1986	1987	1988	1989
United States	0.70	0.75	0.79	0.83	0.95	0.84	0.88	—
Canada	—	—	0.44	0.51	0.51	0.47	0.61	0.59
Canadian R&D expenditures as a percentage of U.S. expenditures				56	61	54	54	69

Source: Purvin and Gertz, Inc. and Hycarb Engineering, "Sectoral innovation strategy for the oil and gas industry," report prepared for the Science Council of Canada, December 1990, X-1.

The comparison with the United States is worth while because its overall use and dependency on oil and gas are very similar to Canada's. Moreover, as the United States is a substantial net oil importer, it is probably more vulnerable than Canada to shortfalls, although provisions in the Free Trade Agreement suggest that Canada might have to share equally with the United States any shortages on a continent-wide basis.

Table 6 shows that the R&D expenditure of five large U.S. oil and gas companies, expressed as a percentage of operating revenues, vary in the range of 0.4 to 1.4 per cent. The two Canadian companies for which published data were available, Imperial Oil and Shell Canada, had R&D expenditures comparable to those of the five major U.S. companies on which data were obtained.

Table 6. R&D expenditures of U.S. and Canadian oil and gas companies as a percentage of operating revenue (1981-1989)

	1981	1982	1983	1984	1985	1986	1987	1988	1989
United States									
Shell Oil				1.2	1.4	1.1	1.1	1.1	
Amoco			0.7	1.2	1.2	0.7	1.2		
Chevron				0.7	0.9	0.7	0.7	0.7	
Exxon			0.7	0.8	0.6	0.6	0.6		
Mobil			0.4	0.5	0.4	0.4	0.4		
Canada									
Imperial	0.8	0.8	0.7	0.7	0.9	1.1	0.9	0.9	0.7
Shell Canada	0.6	0.6	0.5	0.5	0.6	0.9	1.1	1.2	1.0

Source: Purvin and Gertz, Inc. and Hycarb Engineering, "Sectoral innovation strategy for the oil and gas industry," report prepared for the Science Council of Canada, December 1990, X-1. Purvin and Gertz base their comparisons on annual reports, U.S. public corporate tax statements, and share prospectuses.

Table 7 summarizes industry in-house and contract R&D expenditures from 1985 through 1989. Canadian petroleum companies invested $294 million in R&D in 1988, about 0.59 per cent of industry revenues of $50.2 billion.[73] Petroleum industry R&D expenditures generally fell during the latter half of the 1980s. The only category to show growth from 1985 to 1989 was research contracted abroad, that is, transfers from Canadian companies to fund research performed by foreign parents or affiliates.

Table 7. R&D expenditures of the Canadian petroleum industry (1985-1989) ($ millions)

	1985	1986	1987	1988	1989
In-House	256	167	143	189	187
Contract					
In Canada	39	20	15	20	29
Abroad	41	58	73	77	78
Total	336	245	231	286	294

Source: Purvin and Gertz, Inc. and Hycarb Engineering, "Sectoral innovation strategy for the oil and gas industry," report prepared for the Science Council of Canada, December 1990, VI-7 to VI-9.

Only 17 of the hundreds of energy companies operating in Canada reported R&D expenditures in 1989, a steady decline from the high of 40 in 1981. Factors contributing to the decline included introduction of the National Energy Program, the world price collapse in 1986, and significant price erosion in 1988.[74]

An increasing proportion of in-house R&D efforts is being concentrated on activities likely to bring commercial benefits in a short timeframe. Longer term pre-competitive research is being done mainly via joint industry and/or government research bodies.[75]

Most small to medium-sized conventional oil and gas companies do little R&D. Key individuals in the exploration and production groups monitor developments in the industry through such means as professional associations, professional monitoring services, contracts with service organizations or suppliers, trade fairs, and technical journals. New technology is usually applied by the major firms and becomes available directly or indirectly to the smaller oil and gas firms as it becomes better known.

Table 8 shows ownership and control of the Canadian petroleum industry. Only 36.1 per cent is under the control of Canadian public or private owners. Hence, Canadians have little ability to influence R&D decisions. The control exercised by the Canadian private sector is particularly weak. Therefore, Canada's oil and gas sector may not be in a position to significantly increase R&D investment in the petroleum sector. With 63.9 per cent of the industry under foreign control, decisions to increase R&D investment in Canada's petroleum sector must involve foreign decision makers.

Many oil companies in Canada are subsidiaries or affiliates of international firms. Often the parent company undertakes most of the company's R&D, although it usually has technology-sharing agreements with its affiliates, giving them direct access to results of worldwide R&D efforts. Companies of this sort include Shell, Esso/Exxon, BP, Amoco, and Mobil. Interestingly, the Esso/Exxon Canadian operations have a higher R&D/sales ratio than the parent company.

The major Canadian refining companies have had a strong technical capability, partly as a result of affiliations with integrated multinational corporations. In the 1990s, the Canadian refining industry will need to make additional investment to meet environmental regulations and more stringent

Table 8. Ownership and control of the Canadian petroleum industry (1989)

	Percentage ownership	Percentage control
United States	39.2	44.2
Other foreign	15.9	19.7
Total foreign	55.1	63.9
Canadian public sector	16.1	16.3
Canadian private sector	28.8	19.8
Total Canadian	44.9	36.1

Source: Petroleum Monitoring Agency Canada, *Canadian Petroleum Industry 1989 Monitoring Report*, Supply and Services Canada, 1989, 36.

product specifications. Since similar pressures prevail in the United States, the initiative for many of these developments will probably be taken by the U.S. parents of the large Canadian integrated oil companies. Most Canadian companies will be followers in adapting technology to fit specific Canadian needs.[76] An exception is Esso/Exxon, which conducts most of its environmental research in Canada.

Esso, Shell, and Petro-Canada have research laboratories in Canada. Shell and Esso have upstream laboratories in Calgary. Shell Canada is known throughout the Shell group of companies for its expertise in heavy oil, *in situ* recovery, and sour gas handling and processing. Imperial is recognized throughout the Exxon chain for its expertise in upgrading oil sands and its response to and tracking of crude oil spills. In addition, Syncrude's major R&D laboratory, located in Edmonton, is dedicated to applied research in oil sands operation.

Esso, Shell, and Petro-Canada also have downstream R&D laboratories. Most of their work is internally supported and proprietary. Typical projects include testing products, developing a new grease for cold weather climates, developing lubricants, and improving the quality of gasoline for northern climates.[77]

The large, nonintegrated conventional oil and gas companies affiliated with U.S. companies tend to do little R&D in Canada. Amoco, for example, concentrates all of its R&D in research facilities in Tulsa, Oklahoma and Naperville, Illinois. With the acquisition of Dome, however, Amoco has a commitment to the Canadian government to spend $100 million on R&D in Canada over a five-year period. Most of the research is expected to be in heavy oil and northern technologies.[78]

An indication of the relative scale of the Canadian oil and gas industry can be obtained by comparing the whole of the Canadian industry with Amoco, a U.S. multinational that is the fourth largest U.S. oil company by assets and ranks fifteenth among the world's oil companies in liquids production. Amoco is almost as large as the entire Canadian oil and gas industry. Its success is largely due to a policy of regional concentration (in the Midwest). The company has always been a strong innovator. It was the first U.S. oil company to offer premium unleaded fuel, which it introduced in the late 1950s.

Table 9 details Amoco's upstream activities. Amoco is the largest holder of gas reserves in North America and ranks third worldwide in gas production. It is fully integrated in the United States, ranking fourth in total oil refinery runs. Its refining holdings outside the United States consist only of a small interest in the Singapore Refining Company. Amoco also has a large chemical company and several smaller technology-based companies. In 1988, Amoco completed the acquisition of Dome

Table 9. Amoco oil and gas production and reserves (1985-1989)

	1985	1986	1987	1988	1989
Liquids production (thousands of bbl/d)					
United States	401	394	394	409	390
Canada	52	53	58	80	112
Other foreign	362	362	350	321	345
Total	815	809	802	810	847
Liquid reserves (million barrels)					
United States	1 782	1 560	1 670	1 736	1 686
Canada	22	198	205	399	369
Other foreign	764	666	705	663	691
Total	2 769	2 424	2 580	1 798	2 746
Gas production (million ft^3/d)					
United States	1 869	1 731	1 891	1 905	2 072
Canada	279	257	313	547	829
Other foreign	710	831	797	703	735
Total	2 858	2 819	3 001	3 155	3 636
Gas reserves (billion ft^3)					
United States	9 902	10 270	10 690	12 371	12 254
Canada	2 185	2 211	2 135	4 901	4 566
Other foreign	3 050	2 894	2 575	2 215	2 040
Total	15 317	15 375	15 400	19 487	18 860

Source: Purvin and Gertz, Inc. and Hycarb Engineering, "Sectoral innovation strategy for the oil and gas industry," report prepared for the Science Council of Canada, December 1990, IX-2.

Petroleum, then Canada's largest independent producer, for U.S.$4.2 billion. This acquisition increased both Amoco's North American emphasis and its natural gas orientation because Dome had a strong position in the Canadian gas and natural gas liquids industry.[79]

Amoco's reserves increased substantially in 1988 with the Dome purchase. Dome's gas reserves represented about 20 per cent of Amoco's reserves before the acquisition. In 1988, Amoco also purchased Tenneco's Rocky Mountain area holding for U.S.$900 million. Most of the value of this acquisition was in Tenneco's properties in the San Juan Basin of New Mexico, one of the most prolific gas basins in the world. In addition to conventional reserves, these properties substantially increased Amoco's holdings of coal-seam gas. Improved production techniques and the availability of a U.S. income tax credit have encouraged exploitation of these reserves. Amoco's major foreign holdings lie in the North Sea, Egypt, and Trinidad. Amoco's North Sea activities are heavily weighted toward natural gas, while its net liquids production in Egypt exceeds its Canadian volumes.

Amoco's total liquids output of 847 000 bbl/d is about half that of total Canadian output, and its gas production is about equivalent to total Canadian gas production.

Table 10 summarizes Amoco's research activities, all of them conducted at the company's major research centres in Tulsa, Oklahoma and Naperville, Illinois.

Table 10. Amoco research activities (1985-1989)

	1985	1986	1987	1988	1989
Expenditures ($ million)	196.0	217.0	251.0	272.0	278.0
Employees	1 035.0	1 128.0	1 379.0	1 504.0	1 538.0
Expenditures/revenues (%)	0.7	1.2	1.2	0.7	1.2
Expenditures/net income (%)	10.0	29.0	18.5	13.2	17.3
Expenditures/investment (%)	3.7	6.8	8.4	6.1	8.3
Expenditures/cash flow (%)	4.1	7.8	6.0	6.3	6.9

Source: Purvin and Gertz, Inc. and Hycarb Engineering, "Sectoral innovation strategy for the oil and gas industry," report prepared for the Science Council of Canada, December 1990, IX-4.

Amoco's R&D spending has increased steadily over the past five years, despite large variations in income. Its upstream research, at the Tulsa laboratory, is focused on increasing exploration and production efficiency and productivity. R&D on downstream process and product improvement for both refining and chemical operations, as well as work in production and utilization of synthetic fuels from coal, tar sands, and shale oil, is conducted in Naperville.

Total R&D expenditures of Amoco amount to U.S.$278 million annually. This is close to the total Canadian oil and gas industry R&D figure of C$294 million in 1989. Amoco's R&D as a percentage of revenue is about 1 per cent, compared with about 0.6 per cent for the whole Canadian industry.

Amoco's research activities focus on applied areas with fairly direct ties to operations. An improved fracturing technique for coal seams was developed at Tulsa and put into service in the San Juan Basin. As Amoco's leaded gasoline was phased out, new detergent formulations for gasoline were developed at Naperville. Amoco has used its catalyst research to generate licence income, reported to exceed $20 million annually. This is an illustration of the spread of technology through the refining industry: income is generated from proprietary developments through licensing soon after development. Environmental projects include improvement of gasoline delivery equipment and waste reduction/treatment.

The scope of Amoco's research is similar to that of the Canadian industry, but it is oriented more to applications and to downstream needs. It is also much more centralized, which may not make it an appropriate model for the Canadian industry. But it is noteworthy that this multinational company finds it possible to centralize its substantial and successful R&D program.

Amoco's business strategy has emphasized upstream cost reduction and selective investment in mature areas (onshore United States), new commitments in remote areas with high potential (primarily offshore and foreign), and enhanced exploitation of gas reserves. Exploration efforts in 1989 included wells in the Chukchi and Beaufort seas and new concessions in Myanmar and Pakistan. Intensive coal-seam development and targeted gas-marketing efforts illustrate Amoco's commitment to realizing the full value of its gas reserves.

Amoco's refineries are competitive in the markets they serve, but they are generally not the most efficient or highest conversion plants. Rather, Amoco's downstream strategy emphasizes the values of integration and market focus. Amoco markets mainly in the Rockies and the Midwest, areas accessed by its proprietary product pipeline systems. Most of its U.S. crude production is in areas where it can be transported by Amoco pipelines to Amoco refineries. Control of the pipelines gives Amoco a strong position in controlling crude disposition by third parties. This integration strategy has

made Amoco the dominant competitor in the Rockies and one of the top three or four throughout the Midwest.

There are some observations to be noted in comparing Amoco's R&D strategy with that of Canadian firms. First, its R&D levels are somewhat higher relative to sales. Second, almost two-thirds of Amoco's R&D is focused on new products and downstream applications. Third, its R&D is concentrated in terms of both objective and location. Fourth, its R&D spending has increased steadily over the past five years despite large variations in income, indicating an ongoing commitment to R&D. Fifth, the absolute level of its R&D expenditures is similar to Canada's. The first four of these observations suggest that the Canadian sector's R&D levels are rather low, particularly in light of Canada's unique upstream resource opportunities. The last observation suggests that current Canadian R&D levels are at least justified and not unreasonable if concentrated on commercial payoffs. The major open question is what level of effort would be appropriate in Canada for long-term upstream research.

Private Sector R&D: Case Studies

Imperial Oil Ltd.

Imperial Oil is Canada's largest integrated oil company and is active in all activities of the petroleum industry. In 1989, Imperial was Canada's largest producer of crude oil, fifth largest producer of natural gas, and largest refiner and marketer of petroleum products. The firm also manufactures and sells chemicals and fertilizers and has some interest in coal production. U.S.-based Exxon Corporation owns approximately 70 per cent of Imperial Oil shares, the remainder being publicly held.[80]

Imperial's research centre employs between 600 and 700 personnel. Its R&D expenditures have generally decreased over the last five years, falling from $79 million in 1985 to $71 million in 1989.[81] Excluding investment tax credits, the decline was from $69 million in 1985 to $58 million in 1989.[82] In 1990, however, total R&D spending actually increased to $91 million. This gives the Canadian subsidiary a higher R&D intensity than its parent — unusual for multinationals in Canada.

Esso Resource Canada (ERC), Imperial's upstream arm, spent $47 million in replacing its outdated Calgary research facility with a major new facility, which opened in November 1989. Research there is aimed at developing new exploration and production techniques for conventional crude oil, natural gas, bitumen, and coal. Imperial's other research facility, located in Sarnia, supports the downstream activities of Esso Petroleum Canada (EPC) and Esso Chemical Canada.

ERC also participates in research on the recovery of bitumen deposits in Alberta through its interests in Syncrude, which maintains research facilities in Edmonton. Through OSLO, ERC is engaged in determining the most efficient, cost-effective method of producing surface-mineable tar sands with mainly existing technology.

Increasingly, Imperial appears to be focusing its R&D efforts on projects with reasonable expectation of success in the foreseeable future. Funds from Imperial also allow some universities and other research bodies to do more theoretical research that may not have a definite commercial application. Such projects represent less than 5 per cent of Imperial's net research expenditure. The downstream sector appears to have many projects under way at the university level.

EPC and ERC research facilities do the bulk of Exxon's research on lubricants and oil-spill tracking and clean-up; they also carry out much of Exxon's environmental research. Lower oil prices have reduced the emphasis on projects that support production from frontier sources.

Imperial's R&D efforts are coordinated with Exxon's overall R&D. Research agreements with Exxon provide for performance of technical and engineering work, exchange of technical information, and assignment and licensing of patents.

Shell Canada Ltd.

Shell Canada is one of the largest integrated oil companies in Canada. In 1989, it was the second largest producer of natural gas, the 10th largest producer of crude oil, and a major player in manufacturing, distributing, and marketing refined petroleum products and petrochemical products. Shell is also one of the largest producers of sulphur in Canada and was the largest natural gas producer until Amoco Canada purchased Dome Petroleum.[83]

Shell Canada is part of the Royal Dutch Petroleum group of companies. The major shareholder is Shell Investment Ltd. (which is owned 100 per cent by Shell Petroleum N.V.); the remaining shares are publicly traded. Unlike many major oil companies in Canada, Shell Canada does not have a strong association with Shell Oil, its U.S. affiliate. Shell Canada operates two research centres, one in Oakville, Ontario and the other in Calgary, Alberta. In 1987, Shell Canada spent $48 million on R&D.

Much of Shell Canada's research is devoted to sour gas processing in support of its stated target of zero emissions of sulphur dioxide or 100 per cent conversions of hydrogen sulphite. Shell Canada leads the Shell group of companies in sour gas expertise. Like other major oil companies, Shell Canada often works on adapting internationally developed technology to Canadian requirements.

All research in the Shell group of companies must have a business unit sponsor. Pre-competitive research in such areas as biotechnology and artificial intelligence is sponsored at the university level. For example, Shell Canada funds hydrogen research at the University of Calgary.[84]

Shell Canada has a research cost-sharing agreement with Shell Internationale Research Maatschappij B.V., a Netherlands company that is a wholly owned subsidiary of Shell Petroleum N.V. Under this agreement, Shell Canada shares research costs and has the right to use technology developed by Royal Dutch/Shell laboratories around the world.

Husky Oil Ltd.

Husky is a privately held company effectively controlled by two principal shareholders, NOVA Corporation of Alberta (43 per cent) and Union Faith Canada Holdings Limited (43 per cent), a holding company within the umbrella of Hong Kong-based Hutchison Whampoa Limited. Nine per cent is held by VHHC Holdings Inc.; the remaining five per cent is held by a Canadian financial institution. Both NOVA and Hutchison Whampoa are publicly traded companies.

Husky is an integrated oil and gas company whose North American assets and activities are concentrated in western Canada. It also has interests in the Whiterose and Terra Nova oil fields off Canada's east coast. Internationally, Husky has interests in Libya, Indonesia, Papua New Guinea, Vietnam, and Australia. Husky is active in the petroleum product market, selling its products directly to a wide range of wholesale and retail customers.[85]

Until 1990, Husky was a 50 per cent participant in the NOVA/Husky Research Centre (NHRC). When NOVA acquired Polysar in 1989, it also bought Husky's share of NHRC. Husky can now utilize the facility's services solely on a contract basis. NHRC is devoted to basic and applied research in support of NOVA and its affiliated companies.

Husky's wholly owned subsidiary, HRI Inc., specializes in the development and licensing of advanced technologies for producing environmentally clean fuels from fossil fuels. These include heavy crude oils, high-sulphur coals, and heavy oil. Coal liquefaction technologies are also part of HRI's area of expertise.[86]

Much of the upstream R&D, especially in the geology and geophysics, takes place at outside facilities. Over half of external expenditures are in joint industry consortia. Downstream projects are related to hydrocarbon processing in support of Husky's upgrader, asphalt research, corrosion, and pipeline projects. A large and growing percentage of total R&D expenditures is devoted to environmental concerns.

Like many of the participants surveyed for this report by Purvin and Gertz, Inc. and Hycarb Engineering, Husky has developed a stricter bottom line or business sponsorship approach to R&D. Sponsored R&D projects are now more focused, with less emphasis on longer term and theoretical concerns. Husky also ensures that the operations staff member who will have to implement the technology is included on the R&D project team. This helps speed up integration of the technology with Husky's operations.[87]

Provincial Government Support of R&D

Provincial governments in eight provinces have research organizations, and several of these support substantial oil- and gas-related research projects.[88]

The Alberta Research Council, for example, undertakes research in a number of areas relevant to the changing concerns of the oil and gas industry. These include bitumen recovery, hydrocarbon upgrading, and various geological studies aimed at delineating all provincial hydrocarbon resources. It also operates gasoline- and oil-testing laboratories and does research in artificial intelligence, robotics, and the environment.

The Alberta Oil Sands Technology and Research Authority (AOSTRA) remains a major research supporter, although its expenditures fell dramatically from $219.3 million in 1986 to $27.5 million in 1990. AOSTRA, a provincial Crown corporation, has been involved in a wide variety of research projects including *in situ* and enhanced recovery, mining, extraction, and upgrading. Technology developed by AOSTRA is freely available to industry. Major areas of emphasis include numerous joint *in situ* pilot projects operated by various companies, such as Amoco, Bow Valley, Husky, BP, Shell, Unocal, and Mobil.

British Columbia Research supports research in natural gas use as a vehicle fuel.

The petroleum division of the Saskatchewan Research Council has a staff of 30 (out of a total SRC staff of 200). It conducts research in enhanced oil-recovery techniques for conventional and heavy oils, upgrading, and oil emulsions and is active in carbon dioxide research.

ORTECH, the former Ontario Research Foundation, performs energy-related research, including research into alternative fuels at its Advanced Engine Technology Centre. The Ontario Ministry of Energy also supports the ENERSEARCH program, which provides R&D funding for Ontario companies in such areas as fuel research and evaluation and energy-efficient industrial processes.

Federal Government Support of R&D

Federal research organizations that provide support to oil- and gas-related R&D include Energy, Mines and Resources Canada (EMR), particularly the Canada Centre for Mineral and Energy Technology (CANMET), and the National Research Council of Canada through its Industrial Research Assistance Program (IRAP).

The federal research and development program in energy, which includes oil and gas, is noteworthy for the interdepartmental nature of the project selection process. All relevant federal departments participate in the Panel on Energy R&D, or PERD, to establish consensus on the specific energy R&D proposals that the government will support. Every few years, the panel returns to Cabinet for re-approval of the program and its objective, which is currently "to provide the science and technology for a diversified economically and environmentally sustainable energy economy."

Although EMR has the major role in energy R&D, 11 other departments are significant partners. The PERD program is divided into a suite of "tasks" and, below them, "programs," each of

which has a review committee to guide funding recommendations. Advice from industry is actively sought and considered.

The PERD program funds R&D relating to the upstream (oil sands, heavy oils, petroleum geoscience, enhanced oil recovery (EOR), and frontier oil and gas development) and to the downstream (upgrading, refining, and use) oil, gas, and refining industries.

In these fields the federal government has a number of responsibilities:

- to evaluate national hydrocarbon reserves and resources for policy purposes and to meet international agreements;
- to provide an improved understanding of the environment for better informed and more timely environmental impact assessment;
- to develop codes, standards, and regulations that protect the environment, workers, and the public, and that respect the needs of the industry;
- to improve essential services, such as weather and marine forecasts and hydrographic charts, for which the federal government is legally responsible; and
- to share the risks and costs of R&D for the long term (beyond commercial timeframes).

The latter is currently considered critical, as the poor financial performance of the oil and gas industry is reducing its ability to conduct R&D. Examples of such R&D projects include: 1) developing technology to extract more oil from our oil sand reservoirs, heavy oils, and conventional crudes than is currently economically or technically possible; and 2) developing processes to produce more engine-compatible and environmentally benign fuels in existing refineries using changing crude feedstocks.

There is no doubt that the PERD process, in developing extensive partnerships of federal and provincial bodies and industry, is contributing significantly to the science and technology base needed to sustain the oil and gas resource sector.

CANMET, the technology arm of EMR, emphasizes cost-shared programs with industry and is involved in research activities in mining, minerals, metals, materials, and fossil fuels. It has a professional staff of about 300, a research centre and laboratories in Ottawa, an underground mining laboratory in Val-d'Or, Quebec, research facilities in Alberta, northern Ontario, and Nova Scotia, and a regional office in British Columbia. A new energy diversification lab is being established in Varennes, Quebec.

NRC has IRAP representatives located across the country. The program provides technology support for smaller Canadian companies, typically on a cost-shared basis.

Technology Opportunities for the Industry

Despite a substantial focus in Canada on megaprojects, such as tar sands, Arctic exploration, and frontier pipelines, Canadian goods and services are not widely used in international activities.[89]

There is, however, evidence of expanding international opportunities for Canadian technology services and equipment. Further attention should be focused on oil- and gas-related services, especially in the high-technology area, where products, services, and technology are sold on a basis that includes quality and performance, not just cost.[90]

To support the development of these service opportunities, the industry should expand its contracting-out options, encourage divisions of larger firms to undertake more responsibility for profit-making ("contracting-in"), support the efforts of small and medium firms to market services and specialized equipment abroad, and develop the management capability to be a full-service sector.

Among the many opportunities for marketing Canadian innovation in the oil and gas sector, four particularly promising ones are refining technology to handle heavy crude, *in situ* tar sands oil-extraction systems, ultrasour gas production, and downstream gas processing.

For technical readers, an appendix to this report that provides greater details of specific opportunities in Canadian R&D programs is available from the Science Council on request.

Refining

The projected decline in the supply of Canadian light sweet crude oil means that refineries will have to process heavier oil, with higher sulphur contents. The ability to utilize heavier crudes will give a refiner a competitive edge over those continuing to process lighter crudes. With the exception of Imperial's refinery in Sarnia, which has a fluid coker, most Canadian refineries have little heavy, sour crude processing capacity.

The change from light sweet crudes to heavy sour crudes presents two kinds of problems. The higher sulphur levels create problems with respect to equipment corrosion, regularity of loadings (e.g., consistency of operations), sulphur recovery, and air emissions. The difference in yield structure generally results in a need to increase conversion capacity. This opens up a wide range of R&D opportunities.[91]

A particular challenge is the upgrading of Athabasca tar sands. This involves the same processes as in heavy oil upgrading. Clays found in Athabasca tar sands may cause problems in some processing schemes, as experienced by Gulf in developing its solvent donor process. Also, the tar sands have a lower API[92] index and have higher sulphur and metals contents than heavy oils, causing additional processing requirements.[93]

In Situ *Tar Sands*

The only proven technology for extracting oil (bitumen) from tar sands is strip mining followed by hot-water processing. The mining operation can be accomplished only where layers of tar sands are near the surface, allowing removal of overburden without excessive costs and then direct extraction of the bitumen and sand by huge draglines. Canadian tar sands are estimated to contain proven recoverable reserves of about 22.8 billion barrels of oil if this technology is used.

In situ extraction technology refers to a practical technique for extracting oil from the tar sands without moving the sands from their existing location. The bitumen, like conventional oil, must be extracted directly from its underground reservoirs. The principal method is to inject steam into the sands to heat the bitumen and reduce its viscosity, thereby allowing it to flow up the wells under pressure.

Although the technology has yet to be proven commercially, extraction of oil from tar sands by these techniques would considerably improve Canada's energy outlook because of the sheer volume of oil in Canadian oil sand deposits. The quantity of crude oil in the Alberta tar sands is usually estimated at 900 billion barrels, roughly as much as the world's total proven conventional reserves. According to EMR, 55 to 170 billion barrels of oil might be ultimately recoverable by *in situ* methods.[94]

Ultrasour Gas Production

In recent years, many Canadian companies have gained experience in handling and processing sour gas. In Alberta, reservoirs have been discovered with a hydrogen sulphide content in excess of 90 per cent. Production of these fields will require the development of new circulating solvents that prevent corrosion from the disposition of sulphur and hydrate under severe climatic conditions. Also needed will be systems for disposing of fluids resulting from the production techniques. The most recent advance in ultrasour gas production is Shell's pilot plant at the Bearberry field, about 15 kilometres northwest of Sundre. Husky has an ultrasour field, Panther, in an earlier stage of development.[95]

Downstream Gas Processing

Downstream opportunities exist to develop fuels for high-performance engines and products that meet more rigid environmental standards. Methanol fuels represent a major option for Canada, given our large reserves of natural gas. However, greater experience is needed in handling this corrosive substance. One company had to virtually rebuild a methanol plant, because of serious degradation of facilities after only a few months' operation. The former Ontario Research Foundation conducted some interesting experiments in blending methanol with diesel fuel in compression-ignition engines but has now apparently given up.

Conclusion

It is not possible, in early 1992, to define either an optimum Canadian technology strategy or optimum Canadian levels of R&D in the oil and gas sector. Moreover, at current low real prices for petroleum, it is most unlikely that private sector resources alone would be adequate to support an optimum strategy, if it could be defined.

The essential problem that Canadian firms and governments face in identifying an appropriate level of resources for R&D in the oil and gas sector is that future technological requirements in this sector could be seriously distorted because OPEC has the potential to act as a monopoly producer and to set oil prices without regard to conventional market discipline. Artificially high oil prices would be the most likely action, although OPEC could effect a sharp drop in prices to drive non-OPEC oil producers out of business. So long as the price can be manipulated in this way, no-one can project with assurance what the ideal level of R&D spending in the sector should be, because the payoff could well be dependent on factors beyond commercial influence.

The problem is especially significant for Canada because Canada could potentially provide petroleum energy to the world on a much larger scale than is possible today. But Canada could only do this if higher oil prices and technological developments make it commercially viable to bring its unconventional resources and frontier reserves into production. Although substantial R&D is under way in Canada in the oil and gas sector, and still more could usefully be carried out, uncertainties about long-term oil and gas supply and demand make it impossible to determine the likely returns to such investment, particularly within any commercial timeframe.

Energy conservation and substitution further complicate oil-supply investments. Potential still exists for much more energy-efficient transport and heating systems, some of which, like electric vehicles, do not require petroleum for fuel.

A new approach is required to set an R&D agenda in this sector. The logical option for managing the contradictions in objectives this sector faces would be to develop a concerted action plan that defines the roles of resource companies, refiners, research institutions, Canadian federal and provincial governments, and overseas governments. This would ensure that research efforts are coordinated and costs are shared equitably. This plan would have to specify technology goals, memoranda of understanding between all the players, and reasonable accountability levels.

Such an action plan does seem feasible, however, in light of the existing structure of the global and Canadian oil and gas sectors. First, globally, the sector relies on an adopt and adapt technology strategy, with an effective *de facto* division of labour between firms in R&D. No one firm attempts to do the full range of currently feasible R&D. This existing division of labour could provide a basis for more formal cooperation. Second, much, but not all, of the Canadian sector is foreign-owned. Accordingly, overseas firms already have major stakes in Canada and would likely have an interest in pursuing an option that could render these investments more valuable in the long run. On the other hand, Canada would still retain its own stake in the negotiations through the domestically based firms. Third, given Canada's unconventional supply potential, it is in the interests of governments, both within Canada and abroad, to ensure that the basis for continental oil supply is at least available if required.

Appendix: Framework for Technology Strategies

As part of the methodology for analysing each sector, the Science Council of Canada sought whenever possible to assess company technology strategies according to the following framework:

	adopt and adapt	innovation	breakthrough
product			
process			

Strategy Classes

Adopt and adapt: Acquire a technology and adapt it to serve as a competitive platform.

Innovation: Incrementally improve on winning technology to get greater market share or maintain competitive edge.

Breakthrough: Seek to create a discontinuity in the marketplace, thereby leaping ahead of the competition.

The company case studies generally looked for at least seven key dynamics influencing a company's technology strategy:

- three internal dynamics:
  - competitive position,
  - capacity for innovation, and
  - strategy and vision; and
- four external dynamics:
  - customer demands,
  - competitive rivalry,
  - supply condition, and
  - available technology.

The methodology also incorporated essentially a three-step process for each sector. In the first step one or more contractors analysed the main elements in the competitive and R&D performance of the Canadian sector and its leading foreign competitors. The second step included evaluation of the contract report(s), discussion with contractors and other experts, additional in-house research, and preparation of a draft Council report. In the third step, external reviewers commented on one or more drafts of the Council report, which were then revised and refined as required, drawing on the advice of the liaison person for that sector on the Steering Committee (see Acknowledgements). For some sectors, the third step also involved several external reviewers in a small workshop, one part of which

helped define some elements of a potential action plan for the sector. The report was then submitted for final approval to the Executive Committee of the Science Council, before being forwarded to Industry, Science and Technology Canada.

Notes

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39. Purvin and Gertz, Inc. and Hycarb Engineering, I-2.

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